Liquefaction Assessment of Reclaimed Land at CentrePort

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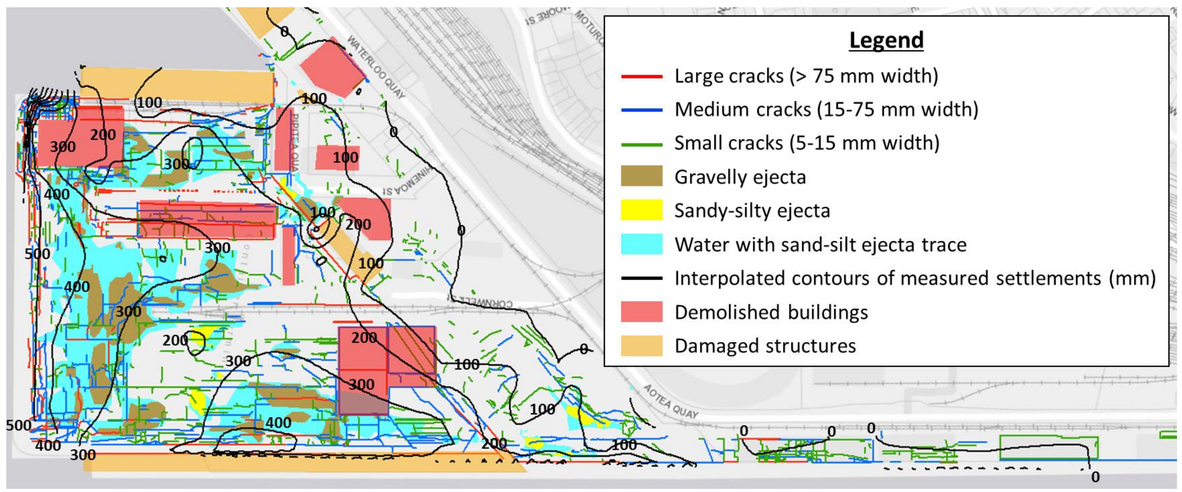
MOTIVATION

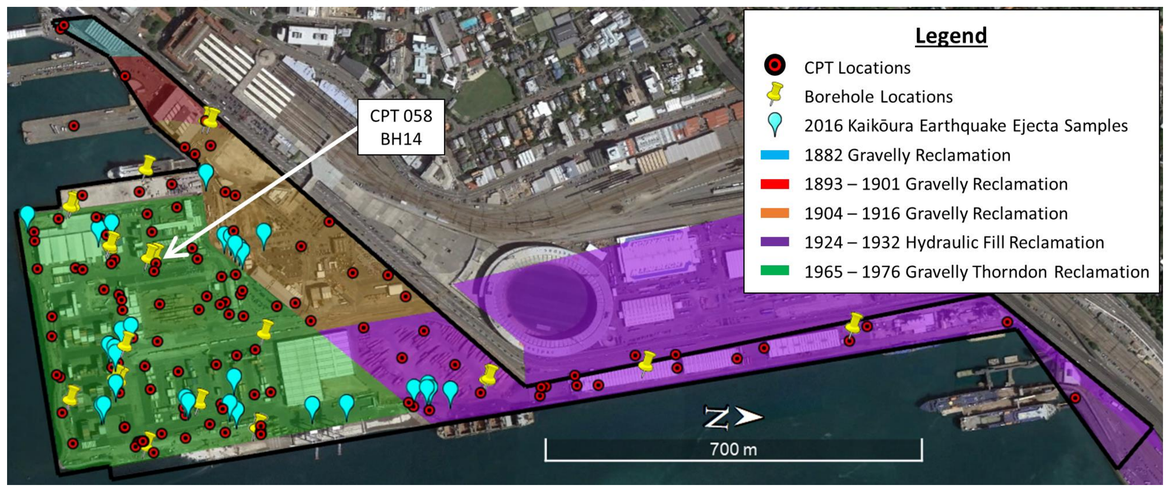
- 2016 M_w7.8 Kaikōura earthquake caused extensive liquefaction and damage to land and structures at CentrePort, Wellington.
- Damage observations provide an opportunity to evaluate and scrutinise current liquefaction procedures for non-standard soils (e.g. gravelly fill and silty soil).



Summary of liquefaction damage from the 2016 Kaikōura earthquake.

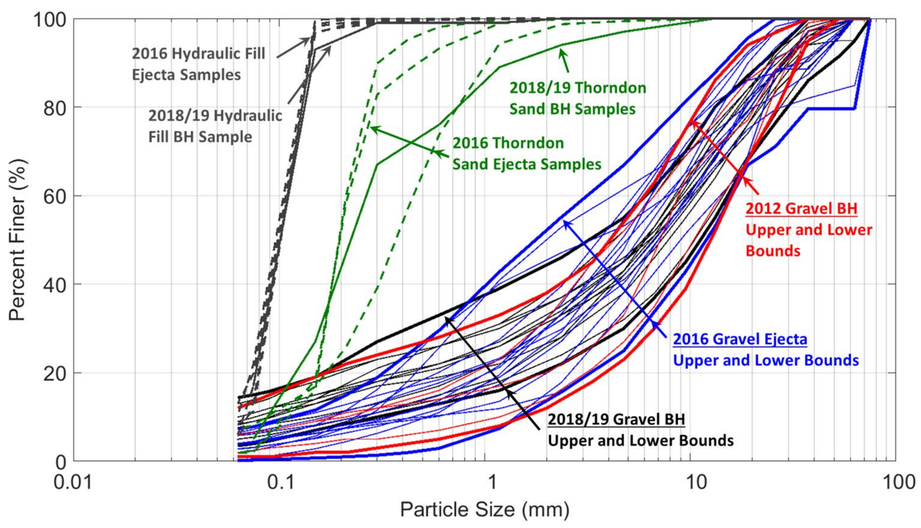
SITE DESCRIPTION

- Different construction methods and materials used for the reclamations: end-tipped gravel-sand-silt mixture; hydraulically-dredged silt and sand
- Various ageing effects: constructed from the late 1800's to 1976
- Reclamation fill varies in depth from 5 m to 22 m
- High-quality CPT (cone penetration test) characterisation of the fills



Map of CentrePort with reclamation zones and key site investigations.

SOIL CHARACTERISATION



Grain-size distribution curves of pre- and post-earthquake soil samples and ejecta samples collected at CentrePort. Gravelly fill contains as much as 70% gravel-sized particles, but at least 30% sand and non-plastic silt that control the soil matrix.

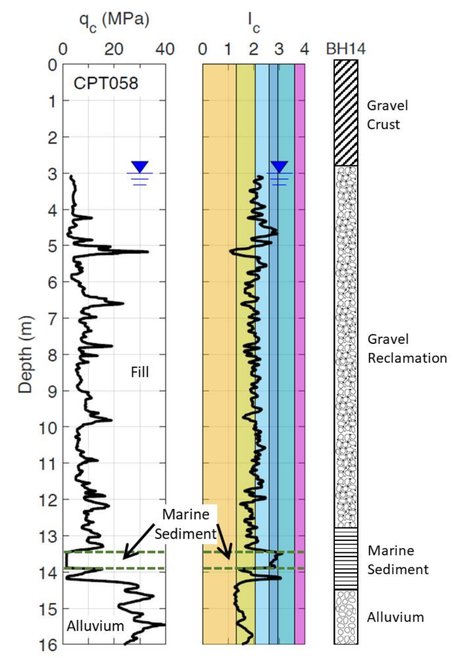
SITE CHARACTERISATION

Gravelly fill characteristics:

- CPT q_c = 6-8 MPa & I_c = 1.9-2.3 correspond to silty sand behavior, not gravel behavior
- Spikes in q_c (e.g. 5.2 m and 6.6 m depths in CPT058) reflect localised increase in tip resistance due to gravel-size particles

Hydraulic fill characteristics:

- Two distinct soil types characterised:
  - Silty sand: q_c = 3.7-4.9 MPa & I_c = 2.0-2.1
  - Silts and clays: q_c < 2.0 MPa & I_c > 2.6
- Deposited in intermittent layers (few cm to m-thick) with limited horizontal and vertical continuity

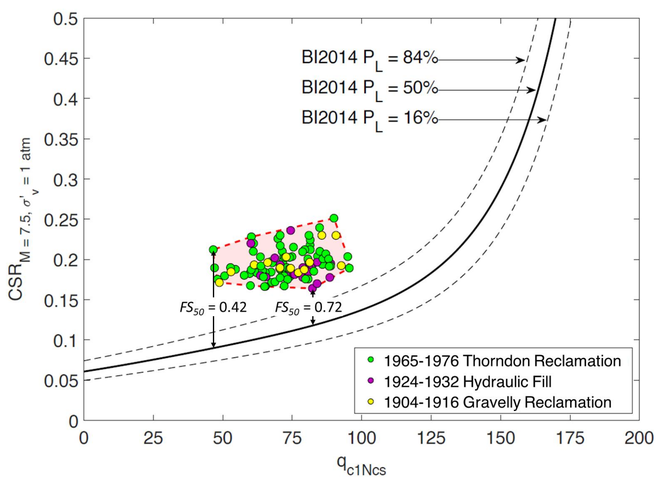


CPT & log of Thorndon gravelly fill.

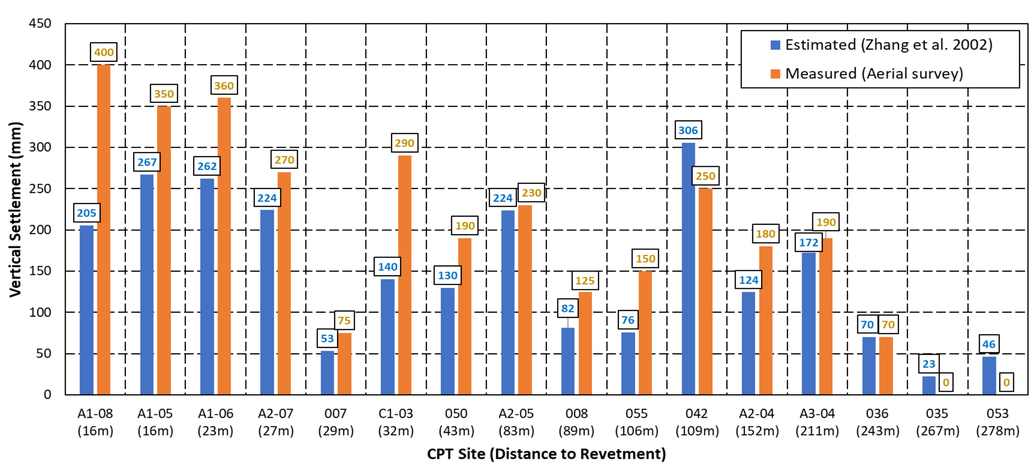
SIMPLIFIED LIQUEFACTION ASSESSMENT

Key findings from liquefaction triggering and vertical settlement estimates:

- Triggering of liquefaction estimated across all reclamation zones; consistent with observations
- Triggering analysis alone doesn't discern differences between the severity of liquefaction
- Calculated settlement estimates perform well for CPTs in free-field conditions (> 60 m from the edges)
- Large underestimation of settlements at CPTs < 25 m from the edge (areas affected by spreading)



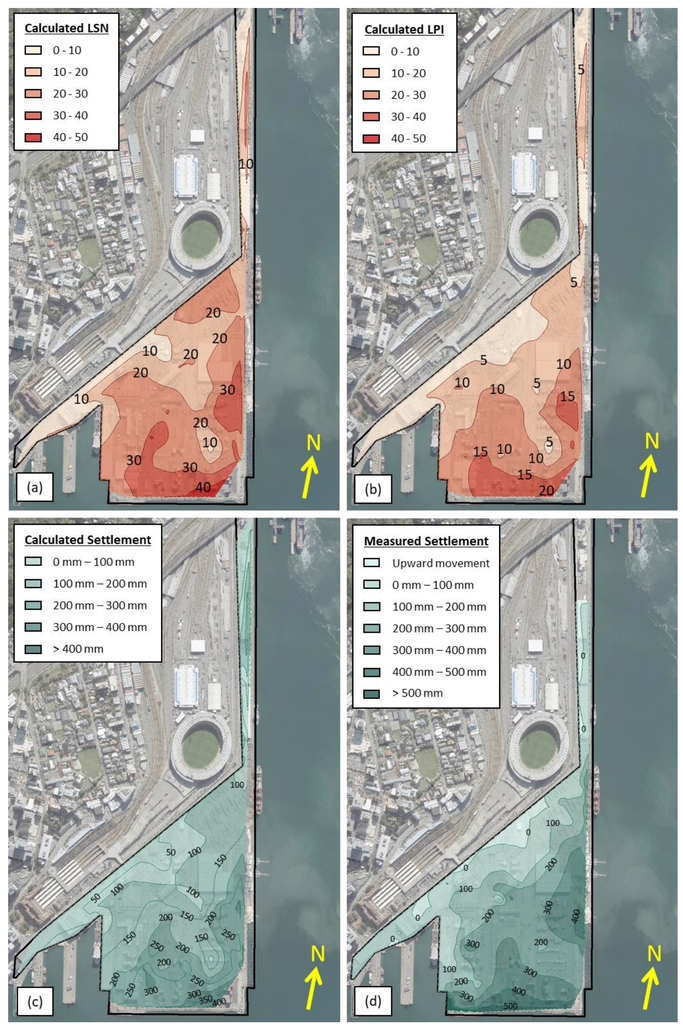
Liquefaction triggering results.



Estimated settlements compared to measured vertical displacements.

Key findings from mapping of results:

- LSN and LPI correctly show trends of more damage at southern end of the port, and minor settlement at the northern end; consistent with observations
- Inconsistencies between estimated and measured settlement trends (e.g. overestimated in the gravelly fill north of the buried seawall) due to simplifications adopted in the analysis



Interpolated contours of: (a) Calculated LSN; (b) Calculated LPI; (c) Calculated vertical settlement estimates; and (d) Measured vertical movement.

PAPERS OF THIS STUDY:

[1] Cubrinovski M, Bray JD, de la Torre C, Olsen M, Bradley BA, Chiaro G, Stocks E & Wotherspoon L (2017). Liquefaction Effects and Associated Damages Observed at the Wellington CentrePort from the 2016 Kaikōura Earthquake, *Bulletin of New Zealand Society for Earthquake Engineering*, **50**(2): 152-173.

[2] Cubrinovski M, Bray JD, de la Torre C, Olsen M, Bradley BA, Chiaro G, Stocks E, Wotherspoon L & Krall T (2018). Liquefaction-Induced Damage and CPT Characterization of the Reclamation at CentrePort Wellington, *Bulletin of the Seismological Society of America*, **108**(3B): 1695-1708.

[3] Dhakal R, Cubrinovski M & Bray JD (2020). Liquefaction Assessment of Reclaimed Land at CentrePort, Wellington, *Bulletin of the New Zealand Society for Earthquake Engineering*, **53**(1): 1-12.

[4] Dhakal R, Cubrinovski M & Bray JD (2020). Geotechnical Characterization and Liquefaction Evaluation of Gravelly Reclamations and Hydraulic Fills (Port of Wellington, New Zealand), *Soils and Foundations*, in press.